Shear Localization in Metallic Glasses

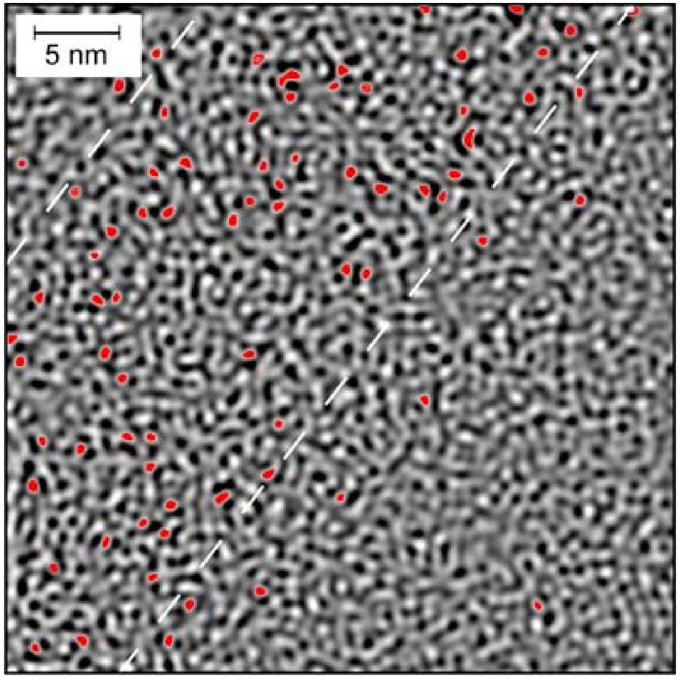
Todd Hufnagel, Johns Hopkins University, NSF Grant #9875115

Nanometer-scale defects in shear bands

- Project goal is to develop understanding of deformation of bulk amorphous alloys, which are new high performance alloys with noncrystalline structures.
- Void-like defects in shear bands, approximately one nanometer in diameter, identified (image at right).
- Voids appear to be due to the coalescence of excess "free volume" when the stress driving the shear band is removed.
- Provides verification of "free volume" model for shear localization.

J. Li, Z. L. Wang, and T. C. Hufnagel. "Characterization of nanometer-scale defects in metallic glasses by quantitative high resolution transmission electron microscopy." *Phys. Rev. B* **65**, 144201 (2002).

J. Li, F. Spaepen, and T. C. Hufnagel. "Nanometer-scale defects in shear bands in bulk metallic glasses." *Phil. Mag. A* (accepted).



High resolution transmission electron micrograph of shear band in a metallic glass (defects are highlighted).

Bulk amorphous alloys are promising new high performance structural materials because the combine high strength, good toughness, large elasticity, and processing flexibility. Amorphous alloys are presently used in sporting goods (golf clubs) and are under consideration for other advanced applications.

The mechanical behavior of these non-crystalline alloys is quite different from that of conventional (crystalline) alloys, due to the differences in atomic-scale structure. For instance, in crystalline alloys, deformation is governed by the motion of defects (dislocations) in the structure. An amorphous material has no such defects, so deformation must occur by another mechanism. The goal of this research project is to develop an understanding of these mechanisms, by using electron microscopy to reveal details of the structure and associated defects inside shear bands (regions of localized plastic deformation).

We have identified the presence of nanometer-scale voids inside shear bands in metallic glasses. These voids appear to result from the coalescence of excess “free volume” once the shear stress driving the shear band is removed and the plastic deformation stops. This provides direct strong evidence for the free volume model of plastic flow in shear bands metallic glasses. The presence of these defects may also explain some of the other features of shear bands, such as why deformation occurs on previously formed shear bands, and why chemical etchants attack shear bands preferentially.

Shear Localization in Metallic Glasses

Todd Hufnagel, Johns Hopkins University, NSF Grant #9875115

Training

- One graduate student (Xiaofeng Gu) and one post-doctoral scholar (Jing Li) have worked on electron microscopy studies of metallic glass structure.
- Two undergraduates (Greg Oberson and Richard Whitney) have worked on design and construction of injection molding equipment for metallic glasses.
- Co-organizer of symposium on shear bands in a variety of materials at the TMS Annual Meeting in Seattle (February, 2002).

Baltimore Polytechnic senior Dallas Perry collecting mechanical properties data for his research project.

Outreach

- Two students from Baltimore Polytechnic High School (Dallas Perry and Harry Malecki) have developed and conducted metallic glass research projects. Harry’s project resulted in a submission to the Intel (formerly Westinghouse) Science Talent Search.
- Co-organizer of National Educator’s Workshop in Gaithersburg, Maryland (October, 2001).

The primary training outcome of the project is the training of one graduate student (Xiaofeng Gu, expected graduation in May, 2003) and one post-doctoral scholar (Jing Li, who is now at Georgia Tech). Several undergraduates have also participated in research. For the past year, Greg Oberson (senior in materials science and engineering; graduated May 2002 and enrolled in graduate study at the University of Maryland) implemented a system for infiltration casting of metallic-glass matrix composites. Richard Whitney (sophomore in biomedial engineering) is installing a new system for injection molding of metallic glasses.

Two students from Baltimore Polytechnic High School have also benefitted from the program. Dallas Perry and Harry Malecki both began as participants in a summer program on materials for sports equipment (in summer, 2000) and continued with us to develop their own research program on different aspects of metallic glasses. Dallas' program explored the effect of temperature on elastic constants of a metallic glass near the glass transition. Dallas finished his program in May 2001 and enrolled as a freshman at the University of Maryland. Harry Malecki developed a longer-term project, recently completed, to investigate the effect of cooling rate during casting on the structural relaxation and mechanical properties of metallic glasses. Harry graduated in May, 2002 and will enroll as a freshman in mechanical engineering at the University of Maryland, Baltimore County (UMBC) in fall, 2002.